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REVIEW

The effectiveness of remote interventions based on digital health technology in kidney transplant recipients: a systematic review

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Abstract

Purpose To evaluate the application effect of remote interventions based on digital health technology in kidney transplant patients through a systematic review.

Design Systematic review.

Methods The databases of PubMed, Embase, Cochrane Library, CINAHL, and Web of Science were systematically searched for randomized controlled trials and quasi - experimental studies on remote interventions based on digital health technology in kidney transplant recipients. The search time limit ranged from the establishment of the databases to September 2024.

Results A total of 10 articles were included, involving 535 patients. A total of 21 clinical outcomes were identified in this study and they were classified into three categories, namely: ① Health-related conditions: Number of steps ($n=1$), heart rate ($n=1$), self-burden score ($n=1$), self-management ability ($n=1$), quality of life score ($n=2$), Self-rating Anxiety Scale (SAS) and Self-rating Depression Scale (SDS) ($n=1$), psychological distress ($n=1$). ② Medication adherence and average tacrolimus concentration: Medication adherence ($n=5$), number of missed doses ($n=1$), medication errors ($n=1$), rejection reactions ($n=1$), average creatinine level ($n=1$), tacrolimus blood concentration level ($n=2$), within-patient variability of tacrolimus ($n=1$), coefficient of variation (CV) of tacrolimus ($n=1$). ③ Medical economic status: Nursing satisfaction ($n=1$), incidence of adverse events ($n=1$), rate of unplanned hospitalization ($n=3$), duration of unplanned hospitalization ($n=1$), one-year medical cost ($n=2$), nursing cost ($n=1$).

Conclusion Remote interventions based on digital health technology can improve the health - related conditions, medication adherence and medical economic status of kidney transplant recipients. However, its impact on tacrolimus concentration remains unclear. Clinical medical staff should fully recognize its positive effects.

Significance

What was known 1. With growing transplant demand and limited health care resources, effective digital health interventions can facilitate self-management and monitoring of kidney transplant recipients. 2. However, the impact of remote interventions based on digital health technologies on patient health improvement is still controversial and requires comprehensive and specific analysis.

This study adds 1. This study identified that remote intervention based on digital health technology can improve health-related status, medication compliance, and medical economic status of kidney transplant recipients. 2. At present, the impact of remote intervention based on digital health technology on the blood concentration of tacrolimus is not clear, and relevant research can be carried out in the future.

Potential impact 1. Clinical healthcare professionals should be fully aware of the beneficial effects of remote interventions based on digital health technologies on patients. 2. Active clinical development in order to improve patients' self-care ability, reduce economic and medical burden, improve quality of life.

Keywords Kidney transplantation · Digital health technology · Remote intervention · Application effect · Systematic review · Evidence - based nursing

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Introduction

Chronic kidney disease (CKD) refers to a disorder of kidney structure and function. As of 2019, the incidence rate of CKD in China reached 13.4% [1]. According to some reports, in 2020, the number of new cases of kidney diseases in China accounted for 2.2% of the global total, and the newly increased number of deaths accounted for 1.8% of the global total [2]. Some patients will progress to end-stage renal disease (ESRD). At present, the main treatment methods for ESRD include peritoneal dialysis, hemodialysis, and kidney transplantation. Among them, kidney transplantation is the most effective treatment for ESRD [3]. Compared with dialysis treatment, kidney transplantation has significant advantages in improving the quality of life and prolonging the survival period [4].

In order to overcome the current shortage of organs, more and more marginal kidneys and kidneys from donors after circulatory death (DCD) are being used in kidney transplantation. At present, living donor kidney transplantation and kidney transplantation from deceased citizens have become the main sources of donor kidneys, but they still cannot meet the demand for donor kidneys [5]. The scarcity of donor kidneys leads to an extended waiting time for transplantation, which in turn increases the mortality rate of patients with end-stage renal disease. In China, there are approximately 100,000 patients waiting for kidney transplantation each year, but only 3% of them can successfully achieve a match and undergo the surgery. Self-care after transplantation for recipients is a long-term process. To improve the long-term survival rate of the transplanted kidney and the quality of life, it is essential to strictly follow the prescribed medication regimen and undergo regular check-ups.

Digital health refers to the provision of healthcare services through portable devices such as smartphones, tablets and computers [6]. Digital health interventions are defined as health-related activities that utilize information and communication technologies, especially the provision of health services and information through the Internet and related technologies [7]. Some studies have shown that the Information-Motivation-Behavioral Skills model (IMB) and the Health Belief Model (HBM)are the most commonly used theoretical frameworks in the process of using digital health interventions [8]. The Information-Motivation-Behavioral Skills model is a theory for changing health behaviors proposed by Fisher et al. in 1992 based on a critical review and integration of various health behavior theories [9]. It identifies three core underlying factors that maintain healthy behaviors, including information, motivation, and behavioral skills. The three factors interact with each other. Individuals obtain information to understand the necessity of healthy behaviors, which in turn motivates them to adopt related healthy behaviors. The Health Belief Model is a model that predicts the influence of personal beliefs on behavior change, mainly including the understanding of disease threats, self-efficacy, as well as facilitating, influencing and limiting factors [10]. This model is widely used to guide health education. It holds that beliefs can influence behaviors, highlighting the dominant role of beliefs in behaviors. It emphasizes that individuals with beliefs related to diseases and health are more likely to adopt healthy behaviors [11]. There is evidence suggesting that digital health remote intervention measures may be helpful in improving patients' self-management behaviors, facilitating communication between clinicians and patients, and providing preventive healthcare services for patients with chronic diseases [12].

In recent years, the demand for transplantation has been continuously increasing, while healthcare resources are limited. Moreover, the self-management knowledge system for patients after discharge is extensive and complex, and patients have insufficient health literacy, lacking timely and personalized health education on self-management [13]. Therefore, effective digital health intervention measures can improve knowledge and self-management behaviors, actively engage individuals in nursing care, and promote the self-management and monitoring of kidney transplant recipients [14]. At present, digital health intervention measures have been widely applied to the post-discharge care of kidney transplant recipients. However, the outcome indicators of application effects discussed in various studies cover a wide range and have significant differences, mainly including aspects such as clinical outcomes, nursing outcomes, self-management assessments, quality of life, and medical indicators. The effects of various studies on related outcome indicators are not yet consistent. For example, the impact of digital health intervention measures on the average level of tacrolimus, coefficient of variation, and intra-patient variability. Some studies have conducted a systematic review on the effectiveness of digital health intervention measures in the self-management of kidney transplant recipients. However, this study only analyzed the clinical and nursing outcomes, lacking a comprehensive analysis of the patients' quality of life and long-term healthcare costs [15]. Therefore, the aim of this study is to comprehensively describe the main characteristics of digital health-based intervention measures through a systematic review, and summarize their application effects in kidney transplant recipients, providing a theoretical basis for the clinical application of digital health intervention measures. Moreover, this study can identify the knowledge gaps in this field and provide guidance for future research directions.

Materials and methods

Study registration

The research was submitted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses criteria and was registered on PROSPERO(CRD42024585621).

Search strategy

The following English databases were searched in accordance with the PRISMA guidelines [16]: PubMed, Embase, Cochrane Library, CINAHL, Web of Science. The search period was from the establishment of the databases to September 2024. For instance, the search formula for the English database Pubmed uses a mix of subject terms and free words: (((kidney transplantation[MeSH Terms]) OR (Renal Transplantation[Title/Abstract]))OR(KidneyGrafting[Title/Abstract])) AND ((((((((((((((((((telemedicine[Title/Abstract]) OR (machine learning[Title/Abstract])) OR (artificial intelligence[Title/Abstract])) OR (mobile health[Title/Abstract])) OR (mobile application[Title/Abstract])) OR (AI[Title/Abstract])) OR (APP[Title/Abstract])) OR (internet[Title/Abstract])) OR (e-health[Title/Abstract])) OR (mobile phone[Title/Abstract])) OR (digital care[Title/Abstract])) OR (big data[Title/Abstract])) OR (video[Title/Abstract])) OR (digital health technology[Title/Abstract])) OR (personalized medicine[Title/Abstract])) OR (smart device[Title/Abstract])) OR (robot[Title/Abstract])) OR (computer-aided diagnosis[Title/Abstract])) OR (decision support systems[Title/Abstract])). To make sure everything was covered, references to the included literature were also checked.

Literature inclusion and exclusion criteria

Inclusion Criteria: ① Study type: Experimental studies or randomized controlled trials. ② The study subjects are individuals who are at least 18 years old and have received kidney transplantation.③Interventions: The experimental group received tele-interventions based on digital health technologies, including phone calls, WeChat interactions, video consultations, and mobile applications. The control group, on the other hand, received standard treatments, such as health education. ④ Clinical outcomes include medication adherence, readmission rates, quality of life, levels of anxiety and depression, and the cost of healthcare. Digital health technologies are used to support home self-management. ⑤ Language: English.

Exclusion Criteria: ① Texts whose entire content is not accessible. ② Duplicate articles. ③ Literature works with a C-grade quality evaluation result. ④ Literature in the forms of case reports, study proposals, guidelines interpretations, etc.

Literature screening and data extraction

Two researchers who have received training in evidence-based methodology independently read the titles and abstracts of the included literature, and then read the full texts. Articles that do not meet the inclusion and exclusion criteria are excluded. In case of any disagreement, a third researcher will be invited to reach a consensus through consultation. Two researchers independently extracted the information of the included literature and cross-checked it. The extracted content mainly included the following information: title, author, publication time, country, research type, sample size, equipment or procedures used in the intervention, intervention measures, intervention duration, intervention outcomes, and statistical analysis results. After the data extraction was completed, a third researcher compared the data extracted by the two researchers. The more consistent the extracted content is, the higher the reliability will be. The researchers synthesized and analyzed the above-mentioned data.

Risk-of-bias assessment

Two researchers independently evaluated the quality of the included literature according to the quality assessment criteria in the Cochrane Handbook for Systematic Reviews and the JBI Quality Appraisal Tool for Quasi - experimental Studies [17]. In case of any disagreement, a third researcher was invited to intervene, and they jointly discussed and decided whether the literature should be included in this study. The evaluation content of RCT includes the following seven items: generation of the random sequence, allocation concealment, blinding, completeness of outcome data, selective reporting of research results, and other sources of bias. The researchers evaluated each item as “high risk of bias”, “low risk of bias”, or “unclear”. The evaluation content of quasi-experimental studies includes nine items such as the causal relationship of research variables, baseline, control, measurement of outcome indicators, and data analysis. Each item is judged as “yes”, “no”, “unclear”, or “not applicable”. The results of the literature quality evaluation include three grades: A, B, and C. Grade A: Completely meets the above standards; Grade B: Partially meets the above standards; Grade C: Completely fails to meet the above standards, and literature of Grade C will be excluded.

Data synthesis

Due to the significant differences in the outcome indicators of various studies, the lack of quantitative data, and the heterogeneity in the design of methodologies and intervention measures, this study mainly presents the research findings through narrative synthesis, and does not conduct a meta-analysis for calculating the adjusted pooled estimates.

Results

Search results and basic characteristics of the included literature

A preliminary search of the database yielded 1,353 pieces of literature. After removing duplicates using the EndNote literature manager, 1,073 pieces of literature remained. Through the initial screening and re-screening of the literature, finally 10 [18–27] pieces of literature met the inclusion criteria. All of them were published English RCT studies. A total of 535 patients were included, with 268 patients in the experimental group and 267 patients in the control group. This study collected data from patients in four countries. Among them, six studies were conducted in the United States, one study was carried out in China, one study was conducted in Sweden, and two studies were performed in Germany. The follow-up time of these studies ranged from 6 months to 12 months. A PRISMA flow chart was drawn, as shown in Fig. 1 specifically. The basic characteristics of the included studies are presented in Table 1.

Risk-of-bias assessment

The Cochrane quality assessment criteria were used to evaluate the quality of the 10 included RCTs. Approximately 40% of the studies clearly described the method of random allocation sequence, and about 20% of the studies reported allocation concealment. All the studies reported the methods of blinding the outcomes, as well as the completeness of outcome data and bias. The results of the literature quality assessment are shown in Table 2.

Intervention mode

Among the 10 pieces of literature included in the analysis, 40% adopted the form of APPs, 40% took the form of telephone calls or text messages, and the remaining two studies involved portable electronic devices that could provide remote guidance and tracking.

Clinical outcomes

This study evaluated 21 clinical outcomes of the application effects of digital health technology - based intervention measures on kidney transplant recipients after discharge. These outcomes were summarized into three aspects: health-related conditions, medication adherence and mean tacrolimus concentrations, and medical economic indicators. Among them, 90.48% (19) of the results were statistically significant. The statistical significance levels and confidence intervals of each clinical outcome are shown in Table 3, and the analysis of their clinical effects and causes is as follows.

Health-related conditions

The health-related conditions mainly include the number of steps taken ($n=1$), heart rate ($n=1$), self-burden score ($n=1$), self-management ability ($n=1$), quality of life score ($n=2$), Self-rating Anxiety Scale (SAS) and Self-rating Depression Scale (SDS) ($n=1$), and psychological distress ($n=1$). The study by Tara O'Brien [22] drew on an interactive approach (SystemCHANGE), which mainly involved setting goals, conducting continuous feedback evaluation, and making adjustments to achieve the goals. It combined this approach with an activity tracker and used a personalized method to maintain individual behavior change goals. The research results demonstrated the feasibility and effectiveness of the intervention of SystemCHANGE plus the activity tracker in increasing the daily number of steps and reducing the resting heart rate. The study by Shuqin Hu [27] found that the nursing intervention based on the Health Belief Model can improve nursing satisfaction, reduce the self-burden score, as well as the scores of the SAS and SDS, and enhance the patients' self-management ability and quality of life. The nursing intervention based on the Health Belief Model mainly promotes the relevant content of healthy behaviors through means such as the WeChat education platform and telephone calls. It provides individuals with correct cognition to establish good health beliefs, understands the patients' barrier factors, offers relevant measures to solve these barriers, enables them to take the initiative to complete healthy behaviors, and ultimately achieves the goal of preventing adverse consequences.

Medication adherence and mean tacrolimus concentrations

Medication compliance and average tacrolimus concentration mainly include medication compliance ($n=5$), number of missed doses ($n=1$), medication errors ($n=1$), rejection reactions ($n=1$), average creatinine level ($n=1$), tacrolimus

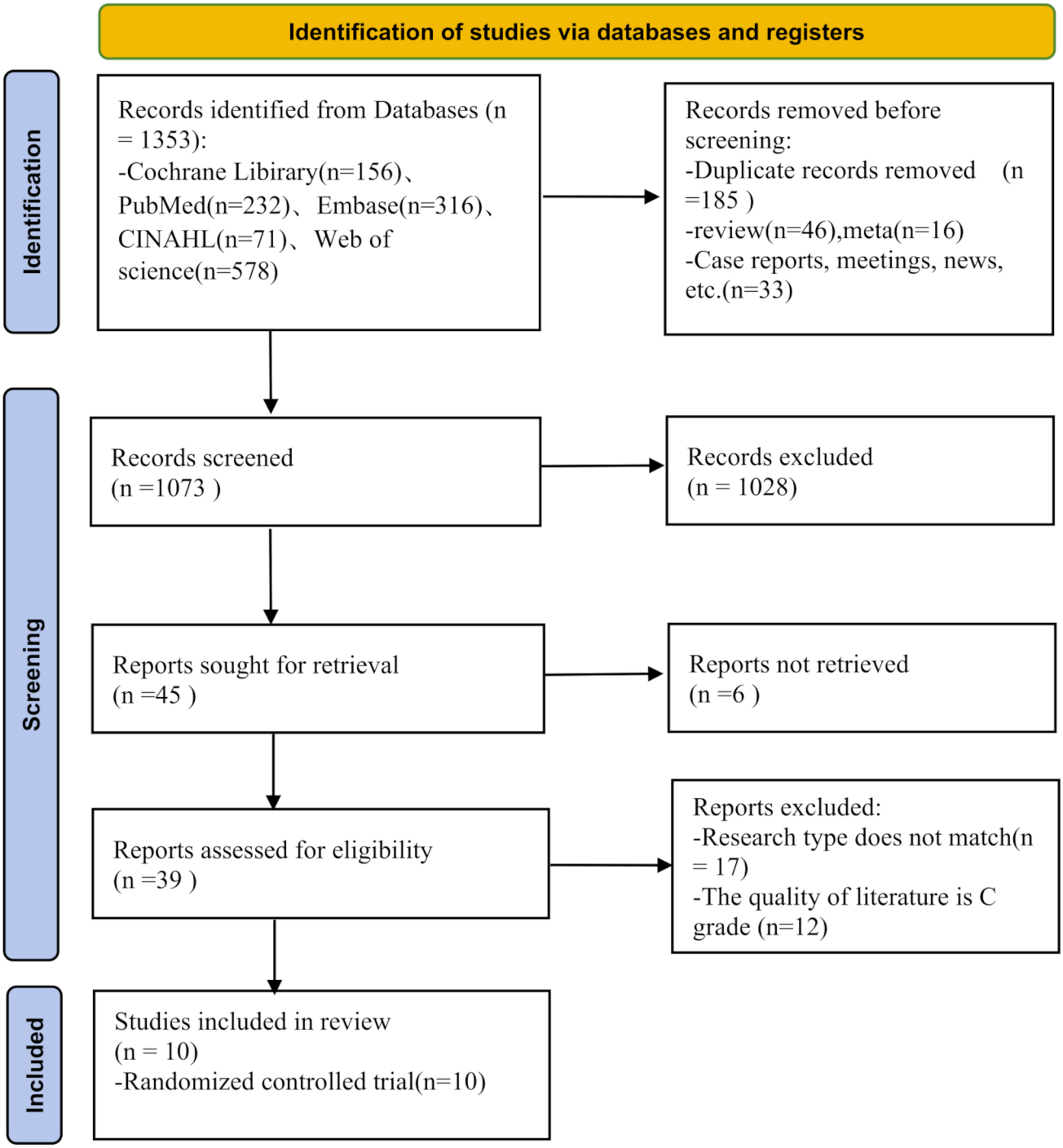

Fig. 1 Literature screening flowchart (PRISMA Flowchart)

blood concentration level ($n=2$), intra-patient variability of tacrolimus ($n=1$), and coefficient of variation of tacrolimus ($n=1$). In five studies, the intervention of digital health technology had a significant effect on medication compliance. One study used an electronic monitoring drug dispensing device to record the date and time of patients' medication intake and monitored it through a web-based application [18]. One study [23] monitored home compliance by using an electronic medication tray and an mHealth application. It could provide patients with tailored incentive reinforcement information, such as visual, auditory, or automated telephone medication reminders, to enhance their ability to comply, thus improving patients' compliance with taking tacrolimus. The research results showed

Table 1 Table of basic characteristics of literature ($n=10$)

Author	Year	Country	Research type	Case source	Experimental group intervention	Control group intervention	Intervention cycle (month)	Intervention form	Measurement index
Jarmo Henriksson [18]	2016	Sweden	RCT	Karolinska University Hospital in Stockholm, Sweden	Use the electronic medication dispenser	Routine nursing	12	Electronic drug dispenser	Compliance, number of missed doses, rejection, and mean P-creatinine and tacrolimus levels
Peter P. Reese [19]	2017	USA	RCT	the University of Pennsylvania	Use bottles to customize alerts (including alerts, text messages, phone calls or emails) plus provider notifications for monitoring	Routine nursing	6	Alerts, SMS, phone or email combinations	Medication adherence, tacrolimus level
Klaus Kaier [20]	2017	Germany	RCT	the Transplantation Center Freiburg	Standard care + additional telemedicine support for case management	Routine nursing	12	Phone, video	Annual medical cost
A. Schmid [21]	2017	Germany	RCT	the UMC Freiburg	Standard care + additional telemedicine support for case management	Routine nursing	12	Telephone, voice mail, SMS service and email	Noncompliance, unplanned hospitalization (rate, length of stay, cost of emergency care), quality of life, psychological distress
Tara O'Brien [22]	2020	USA	RCT	Midwest transplant center	The SystemCHANGE method is combined with the activity tracker	Routine nursing	6	Activity tracker	Step count and heart rate 6 months after surgery
John W. McGillicuddy [23]	2020	USA	RCT	Medical University of South Carolina	Electronic medicine tray and mobile health app	Routine nursing	6	APP	Medication adherence, tacrolimus CV
Haley M. Gonzales [24]	2021	USA	RCT	the Medical University of South Carolina	Usual care + pharmacist-led complementary drug therapy monitoring and management	Routine nursing	12	APP	Incidence of adverse events, hospitalization, medication errors
James N. Fleming [25]	2021	USA	RCT	the Medical University of South Carolina	Routine care + pharmacist-led, mhealth based interventions	Routine nursing	12	APP	Intrapatient variability of tacrolimus
David J. Taber [26]	2021	USA	RCT	the Medical University of South Carolina	Usual care + pharmacist-led complementary drug therapy monitoring and management	Routine nursing	12	APP	Annual hospitalization rate and hospitalization costs
Shuqin Hu [27]	2022	China	RCT	Department of Organ Transplantation, Jiangxi Provincial People's Hospital	HBM (Health belief model) + routine care	Routine nursing	6	Phone, wechat, SMS combination	Nursing satisfaction, self-burden score, self-management ability, quality of life score, SAS, SDS, medication compliance

that the average coefficient of variation (CV) of tacrolimus in the intervention group significantly decreased over 12 months ($P=0.046$). In another study [19], wireless pill bottle monitoring with customized reminders (including alarms, text messages, phone calls, or emails) was used to assess the compliance of tacrolimus. The research results showed that there was a statistically significant difference in the average compliance between groups ($P<0.001$), but there was no significant difference in the average level of tacrolimus. One study found that the nursing intervention based on the Health Belief Model (HBM), which applies by analyzing individual health beliefs through the WeChat education platform, can improve the medication compliance of recipients [27]. Some studies have pointed out that under the digital health technology intervention for one year, there is a significant difference in medication compliance between the intervention group and the control group [21]. Jarmo Henriksson et al. [18]conducted an intervention through an electronic medication dispenser (EMD) in a study to obtain relevant information about patients' compliance. The EMD will send out visual or auditory signals at the prescribed medication time. If the patient does not take the medicine, the sound signal will continue for 120 min. This method can significantly reduce the number of missed doses and the occurrence of rejection reactions in kidney transplant recipients. In a study by Haley M. Gonzales [24], the subjects in the intervention group received supplementary clinical pharmacist-led medication therapy monitoring and management through a mobile health-based application. This was combined with risk-guided remote visits and home blood pressure and blood glucose monitoring. The application provided accurate medication regimens, timely reminders, and investigations of side effects. The research results showed that the incidence of medication errors and adverse events in the intervention group was significantly lower than that in the control group.

Medical economic indicators

The medical economic indicators mainly include nursing satisfaction ($n=1$), incidence rate of adverse events ($n=1$), rate of unplanned hospitalization ($n=3$), duration of unplanned hospitalization ($n=1$), one-year medical cost ($n=2$), and nursing cost ($n=1$). One study [21] carried out case management through remote monitoring and real-time video consultations. The process mainly included initiation, assessment, planning, contact, monitoring, and evaluation. This approach enables personalized diagnosis and treatment, allowing for timely understanding of patients' health conditions. As a result, it can reduce the rate of unplanned hospitalizations, the duration of unplanned hospital stays, nursing costs, quality of life, and alleviate psychological distress.

Sensitivity analysis and heterogeneity discussion

In this systematic review, due to the heterogeneity of the included studies and the large differences in the outcome indicators, it was not possible to conduct a quantitative Meta-analysis. Therefore, we adopted qualitative methods to perform a sensitivity analysis on the research results and discuss the heterogeneity, in order to evaluate the robustness and reliability of the results. The 10 pieces of literature included in this study are all randomized controlled trials, and the intervention durations are all relatively long (6 months or more). Moreover, only one study (10%) was conducted in China, and the rest were carried out in European and American countries. Therefore, discussions on the research design, intervention duration, and geographical location were not conducted. Firstly, the intervention measures included in this study cover various forms of digital health technologies, such as mobile applications, remote monitoring devices, telephones, videos, and so on. These forms of intervention vary in terms of frequency and duration. We have found that despite the differences in the intervention content, all forms of digital health interventions have a positive impact on the health management of kidney transplant patients. Secondly, we discussed separately whether the results of different outcome indicators were consistent. The results showed that the remote intervention of digital health technology has a relatively significant effect in improving health status, medication compliance, and medical economic conditions. However, the impact on the average concentration of tacrolimus still requires further research. Finally, we adjusted the inclusion criteria and only included studies published in the past five years. After that, the application effect of remote intervention of digital health technology among kidney transplant recipients remained significant, indicating that the change of the time range has little impact on the outcomes. Although there are slight differences in the research results of different times and different forms of intervention, the overall effects tend to be consistent, indicating that the application of digital health technology among kidney transplant recipients has universality and effectiveness.

Discussion

This study summarizes the application effect of remote intervention based on digital health technology in kidney transplant recipients. The research results show that the clinical outcomes mainly focused on in the included studies

Table 2 Literature quality evaluation table ($n=10$)

Author	Random allocation method	Allocation scheme hiding	Blind method	Outcome measure blind method	Integrity of the resulting data	Selectively report research findings	Other sources of bias (conflict of interest, small sample size, uneven baseline)
Jarmo Henriksson (2016) [18]	Randomized envelope	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Peter P. Reese (2017) [19]	Random (not described)	unclear	Low risk	Low risk	Low risk	Low risk	Low risk
Klaus Kaier (2017) [20]	Random (not described)	unclear	Low risk	Low risk	Low risk	Low risk	Low risk
A. Schmid (2017) [21]	Randomized schedule	unclear	Low risk	Low risk	Low risk	Low risk	Low risk
Tara O'Brien (2020) [22]	Permutation block randomization scheme	unclear	Low risk	Low risk	Low risk	Low risk	Low risk
John W. McGillicuddy (2020) [23]	Random (not described)	unclear	Low risk	Low risk	Low risk	Low risk	Low risk
Haley M. Gonzales (2021) [24]	Random number generator	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
James N. Fleming (2021) [25]	Random (not described)	unclear	Low risk	Low risk	Low risk	Low risk	Low risk
David J. Taber (2021) [26]	Random (not described)	unclear	Low risk	Low risk	Low risk	Low risk	Low risk
Shuqin Hu (2022) [27]	Random (not described)	unclear	Low risk	Low risk	Low risk	Low risk	Low risk

are the medication compliance after surgery and the average concentration of tacrolimus, health-related conditions, and medical economic indicators of kidney transplant recipients. Regarding the study on the effectiveness of remote intervention with digital health technology for kidney transplant recipients, the findings of this study are similar to those of a systematic review conducted by Saeid Eslami [15]. However, the clinical outcomes focused on in the two studies are not consistent.

Health-related conditions

The results of this study show that remote intervention based on digital health technology can improve the health-related conditions of kidney transplant recipients. Health-related conditions mainly include self-burden scores, self-management ability, quality of life scores, SAS, SDS, and psychological distress. Kidney transplantation can affect the patient's neuroendocrine system and immune system, and thus it leads to certain adverse outcomes for the patient's physical and mental health [28]. Some studies have shown that the prevalence rate of depressive symptoms after transplantation is between 5% and 75% [29]. Depressive emotions can reduce patients' compliance, thereby preventing them from taking actions that can change their lives. In kidney transplant patients, depressive symptoms have a significantly negative correlation with the patients' coping styles towards the disease. Patients with a more positive coping style (actively seeking health-related information) tend to have fewer depressive symptoms after transplantation [30]. Anxiety and depressive emotions can lead to poor health conditions in patients. Some studies have shown that the poor health conditions of recipients not only have a negative impact on their mental health but also affect all aspects of their quality of life [31]. This is consistent with the research conducted by Holscher and others [32].

With the development of medical technology and the popularization of the concept of enhanced recovery after surgery, the hospital stay of patients has been shortened compared with the past. Traditional nursing only focuses on the care during hospitalization and pays relatively little attention to the health management needs of patients after discharge. In order to maintain the long-term function of the transplanted kidney after surgery, kidney transplant recipients need to receive continuous professional medical and nursing guidance after discharge, and actively participate in making choices regarding post-transplant medical care and lifestyle [33]. And the degree to which patients participate in and understand medical choices depends on their level of health literacy [34]. Increasing the understanding of disease knowledge is an important way to improve the level of health literacy. The remote intervention based on digital

Table 3 Statistical significance levels and confidence interval table for clinical results($n=18$)

outcome measures	*p*-values and CI	Tara O'Brien [22]	Jarmo Henriksson [18]	Peter P. Reese [19]	Shuqin Hu [27]	John W. McGillicuddy [23]	Haley M. Gonzales [24]	James N. Fleming [25]	Klaus Kaier [20]	David J. Taber [26]	A. Schmid [21]
number of steps	*P*	0.03									
heart rate	*P*	0.04									
	Test Group CI	[63.10,72.02]									
	Control Group CI	[65.71,74.69]									
medication compliance	*P*			<0.001	<0.05	0.04					0.013
	Rate		97.80%	27%							
	Test Group CI			[15%,40%]							
Number of missed doses	*P*		0.033								
medication errors	*P*						<0.001				
	Total CI						[0.28,0.55]				
rejection	*P*		0.02								
tacrolimus IPV	*P*							0.033			
Tacromus CV	*P*					0.046					
nursing satisfaction	*P*				<0.05						
Self-burden rating	*P*				<0.01						
self-management ability	*P*				<0.05						
quality of life score	*P*				<0.05						
SAS	*P*				<0.01						
	Test Group CI				[53.57,56.29]						
	Control Group CI				[40.05,42.53]						
SDS	*P*				<0.01						
	Test Group CI				[64.34,67.60]						
	Control Group CI				[41.49,44.89]						
adverse event rates	*P*						0.05				
	Total CI						[0.30,0.99]				
Unplanned hospitalizations rate	*P*						0.005			0.007	0.004
	Total CI						[0.27,0.77]				
Unscheduled hospital stay	*P*										0.002
One-year medical costs	*P*								<0.001	0.022	
	Total CI									[0.28,0.91]	

health technology can quickly understand the patients' conditions, provide timely support, and solve relevant problems through applications (APPs), wearable devices, etc. This approach can enhance patients' mastery of transplantation knowledge, build their self-care abilities and confidence, thereby improving their quality of life [35]. Therefore, implementing remote intervention measures based on digital health technology can provide professional guidance for patients after discharge, enhance their self-care ability, promptly detect changes in their physical conditions, and thus enable timely treatment, which is similar to the results of our study [36, 37].

Medication adherence and mean tacrolimus concentrations

The results of this study show that remote intervention based on digital health technology can improve the medication compliance of kidney transplant recipients and the average concentration of tacrolimus. Medication compliance and tacrolimus concentration mainly include drug omission, incorrect medication, rejection reaction and tacrolimus concentration. Patients who have undergone kidney transplantation need to take immunosuppressants throughout their lives to maintain the normal function of the transplanted kidney. However, the use of a large number of immunosuppressants will lead to a decrease in the body's resistance. Therefore, patients' non-compliance with the drug treatment plan will result in missed doses or incorrect medication, leading to acute or chronic rejection reactions or the production of donor-specific antibodies, which may lead to transplantation failure and difficulties in retransplantation [38, 39]. In addition, persistent medication non-compliance may lead to an increase in personal medical costs. However, non-compliance with immunosuppressive drugs is very common, and 1.6 − 96% of kidney transplant recipients show drug non-compliance [40]. Therefore, how to improve the medication compliance of kidney transplant patients has become an urgent problem to be solved. Some studies have found that a stronger positive perception of the disease is associated with better medication compliance [41]. Continuous nursing can enhance patients' ability to perceive their diseases, strengthen medical staff's observation of patients' medication use, and guide patients' medication behaviors. As a result, it can greatly improve patients' medication compliance and their understanding of the medication plan [42]. This indicates that positive and continuous nursing can significantly enhance patients' medication compliance and self-care ability, which is conducive to the survival and functional maintenance of the transplanted kidney, and also of great significance for improving patients' quality of life [43]. And the remote intervention based on digital health technology belongs to continuous nursing. The evidence from a systematic review shows that education, electronic trackers/reminders, and simplified treatment regimens lead to better medication adherence among asthma patients compared to control interventions, which is similar to the findings of our study [44]. The relationship between medication compliance and tacrolimus concentration is controversial, and the possible reasons include differences in research design, sample size, and among the research subjects. In the future, more experimental studies are needed to fill the gap in this regard.

Medical economic indicators

The results of this study show that remote intervention based on digital health technology can improve the medical economic indicators of kidney transplant recipients. The medical economic indicators mainly include the rate of unplanned hospitalization, the duration of unplanned hospitalization, the one-year medical cost, and the cost of unplanned emergency nursing care. According to statistics, the incidence of unplanned readmission in the early stage after kidney transplantation is 24.4% [45], which is much higher than that of patients who have undergone other major surgeries (12%) [46]. The main reasons are surgical complications, infections, acute kidney injury, and acute rejection reactions [47, 48]. Readmission can lead to a two-fold increase in the risk of transplantation failure and an increase in patient mortality [49]. Unplanned readmission not only has a negative impact on the physical and mental health of patients, but also increases the economic burden and restricts medical resources [50]. Some studies have shown that the cost of early readmission has increased by an average of $10,551 [51].

Some studies have shown that the 30-day and 90-day readmission rates of the intervention group are significantly lower than those of the control group. Moreover, poor communication between doctors and patients after discharge will have a certain negative impact, leading to more adverse events and unplanned readmissions [35]. Recent studies have shown that remote intervention based on health technology is an effective and sustainable strategy, which can promote communication between patients and medical staff, improve health outcomes, enhance the quality of life, improve compliance with medical programs, and reduce the costs of some chronic diseases [52]. Although the current evidence regarding its cost-effectiveness is inconsistent, with the increase in demand, the reduction in technical costs, and the realization of long-term health benefits, it is expected to become cost-effective.

Strengths, limitations and prospects

The advantages of this study are as follows: ① A comprehensive and systematic search of relevant databases was conducted, and the included literature is relatively complete. ② This study only included randomized controlled trials, and a quality assessment was carried out on the included literature. As a result, the quality of the obtained results is relatively high, so the risk of reporting bias is low. ③ At present, the research results on the application effect of remote intervention based on digital health technology for kidney transplant patients are not unified. This study has carried out a comprehensive analysis, and compared with previous systematic reviews, it has included recently published literature, so the analysis results are also more abundant.

The limitations of this study are as follows: ① The included studies lack quantitative data on relevant outcome indicators, making it impossible to conduct a meta-analysis. ② There are certain differences in the sample size, intervention duration, and intervention measures of the included studies, which may lead to heterogeneity in the reported results. ③ This study only included studies published in English, which may lead to the omission of high-quality studies written in other languages. ④ Although we have made every effort to be comprehensive when determining the search terms, some studies on interventions using digital health technology may have used different keywords. This may result in our systematic review missing relevant studies.

Suggestions and Prospects: ① Meta-analysis can explore the heterogeneity of various studies and reduce the impact of publication bias. Future studies should fully report the quantitative data of outcome indicators. ② In the future, high-quality, large-sample, multi-center randomized controlled clinical trials should be conducted to improve the generalizability of the research. Longitudinal studies can also be carried out to evaluate the impact of digital health technology on kidney transplant recipients based on long-term follow-up, such as postoperative rejection reactions, immunosuppressive drug management, and quality of life. ③ Currently, the diversity of remote intervention programs in the studies may lead to inconsistent effectiveness evaluations. Future studies should develop standardized remote intervention programs, clearly defining the forms, frequencies, and technical platforms of the interventions. This will help ensure comparability among studies.

Conclusion

The results of this study show that remote intervention based on digital health technology can improve the health-related status, medication compliance, and medical economic situation of kidney transplant recipients, but its effect on tacrolimus concentration remains unclear. Promoting the application of digital health technology among kidney transplant patients can provide an evidence base for clinical practice.

Remote intervention based on digital health technology has important practical significance in clinical practice. Firstly, it can break through geographical limitations and effectively extend the coverage of medical services. Especially in remote areas or environments with scarce resources, it enables patients to receive timely medical attention. Secondly, remote intervention can facilitate doctors' continuous monitoring of patients and early intervention. Through remote data collection and analysis, clinicians can obtain patients' health conditions in real time, thus making more accurate diagnosis and treatment decisions. Generally speaking, remote intervention provides clinicians with a more flexible and efficient way of working, which is conducive to improving the quality of medical care and patients' treatment experience.

The integration of digital health intervention measures with the existing healthcare system has broad potential, and there are various ways of integration. For example, by integrating the data collected by digital health intervention measures (such as smart wearable devices, remote monitoring tools, etc.) with the patients' Electronic Health Record (EHR) system, doctors can obtain patients' health information in real time. This kind of integration helps to provide more comprehensive and personalized treatment plans. Digital health interventions can be integrated with the existing public health system, chronic disease management programs, etc. through health management platforms, helping doctors to carry out personalized health interventions and prevention. By regularly tracking health data, doctors can achieve early identification and early prevention, thereby reducing patients' hospitalization rates and medical costs. Remote diagnosis and treatment services can be integrated into the outpatient processes of the existing healthcare system. Patients can have remote online communication with doctors at home and receive timely feedback on medication, self-management, and follow-up consultations. This can optimize the allocation of medical resources and relieve the pressure on hospital outpatient departments. In conclusion, the effective integration of digital health intervention measures with the existing healthcare system can not only improve the service quality and efficiency of the medical system but also promote the realization of personalized

medicine, enabling doctors to provide more accurate and convenient treatment.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The author(s) declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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